Table 1. Summary of experimental conditions versus the resulting one-dimensional structures.

Morphology	Flow rate of O_2 in 100 sccm of H_2 (sccm)	Microwave power (W)	Pressure (Torr)	Duration (Hr)	Location on the substrate
Nanoscale wires	0.6-10	600-900	30-50	1-12	On top of the micron to millimeter sized gallium droplets near the center of the substrate
Micro scale, well faceted rods	0.6-10	600-900	30-50	1-12	Clustered around the micron to millimeter sized gallium droplets
Nanopaintbrushes	7-10	600-1200	30-60	2-10	Near the edges of the substrate
Micron scale	7-10	600-1200	30-60	2-10	Near the edges of the substrate

The EDX (spectrum not shown) confirmed that the individual nanowires consist of Ga (K_α at 9.3 keV, at 1.11 eV) and O (K_α at 0.53 keV). Figure 3A shows a bright field TEM image of a 100 nm thick nanowire. The HRTEM image in Figure 18 shows a 25 nm thick gallium oxide nanowire. The lattice spacing in HRTEM image also matched that for bulk beta-gallium oxide. The insert in Figure 18 shows the corresponding selected area electron diffraction pattern taken along the [001] zone axis.

The nanowire growth direction was determined to be [110]. Three nanowire samples were examined and the high-resolution TEM results were similar, i.e., structures were devoid of any stacking faults. The absence of stacking faults within the nanowire structures contradicts prior suggestions of structural defect mediated growth mechanisms for one-dimensional structures. For

Table 2. Minimum partial pressures of monoatomic and diatomic oxygen required for 1 nm sized nuclei of the respective oxides at 1000K. Thermodynamic properties were obtained from ref 36. The estimated Gibbs free energy values for overall reactions are indicated in square brackets.

Metal	Overall formation reaction using atomic oxygen	Overall formation reaction using Molecular oxygen	Minimum partial pressure of O required (Torr)	Minimum partial pressure of O_2 required (Torr)
Ga	$2Ga_{(l)} + 3O_{(g)} \rightarrow Ga_2O_{3(s)}$ [ΔG^0 = -1326.2 kJ/mol]	$2Ga_{(l)} + 3/2O_{2(g)} \rightarrow Ga_2O_{3(s)}$ [ΔG^0 = -763.1 kJ/mol]	4×10^{-18}	9×10^{-19}
In	$2In_{(l)} + 3O_{(g)} \rightarrow In_2O_{3(s)}$ [ΔG^0 = -1169.2 kJ/mol]	$2In_{(l)} + 3/2O_{2(g)} \rightarrow In_2O_{3(s)}$ [ΔG^0 = -606.1 kJ/mol]	2×10^{-16}	2×10^{-15}
Al	$2Al_{(l)} + 3O_{(g)} \rightarrow Al_2O_{3(s)}$ [ΔG^0 = -1925.2 kJ/mol]	$2Al_{(l)} + 3/2O_{2(g)} \rightarrow Al_2O_{3(s)}$ [ΔG^0 = -1362.1 kJ/mol]	6×10^{-26}	2×10^{-34}
Sn	$Sn_{(l)} + 2O(g) \rightarrow SnO_{2(s)}$ [ΔG^o = 748.2 kj/mol]	$Sn_{(l)} + O_{2(g)} \rightarrow SnO_{2(s)}$ [ΔG^o = -372.8 kJ/mol]	4×10^{-13}	8×10^{-9}
Zn	$Zn_{(l)} + O_{(g)} \rightarrow ZnO_{(s)}$ [ΔG^o = -435.9 kj/mol]	$Zn_{(l)} + ½ O_{2(g)} \rightarrow ZnO(S)$ [ΔG^o = -248.3 kJ/mol]	2×10^{-14}	2×10^{-11}

The present invention provides a method of synthesizing bulk amounts of highly crystalline gallium oxide tubes, nanowires, and nanopaintbrushes using large gallium pools and a microwave plasma containing atomic oxygen. Direct use of gallium melts in plasma environments allowed bulk synthesis with high nucleation densities and allowed for template-free synthesis of nanostructures with